Harmonic mitigation for AC-drive thruster applications

Ian Evans, of Harmonic Solutions Co UK, discusses some interesting new technology for electric-motor systems that could offer many benefits.

DURING the last five years, there has been a significant increase in AC variable-frequency drives for AC motor speed control in marine applications. Many diesel-electric vessels, such as cruise liners and offshore support and work ships, utilise AC drives for main propulsion, usually variable frequency, synchronous or cyclo-converter types. In addition, the new UK Royal Navy Type 45 destroyers - the first-generation of 'electric warships' - will have two 20MW, 15 phase AIM (Advanced Induction Motors) motors and AC variable-frequency drives for main propulsion. Further, AC drives are now commonly used for ancillary drives, including pump, fan and compressor applications, and AC variable-frequency drives are increasingly used for thruster applications in the power range 350kW to 2500kW.

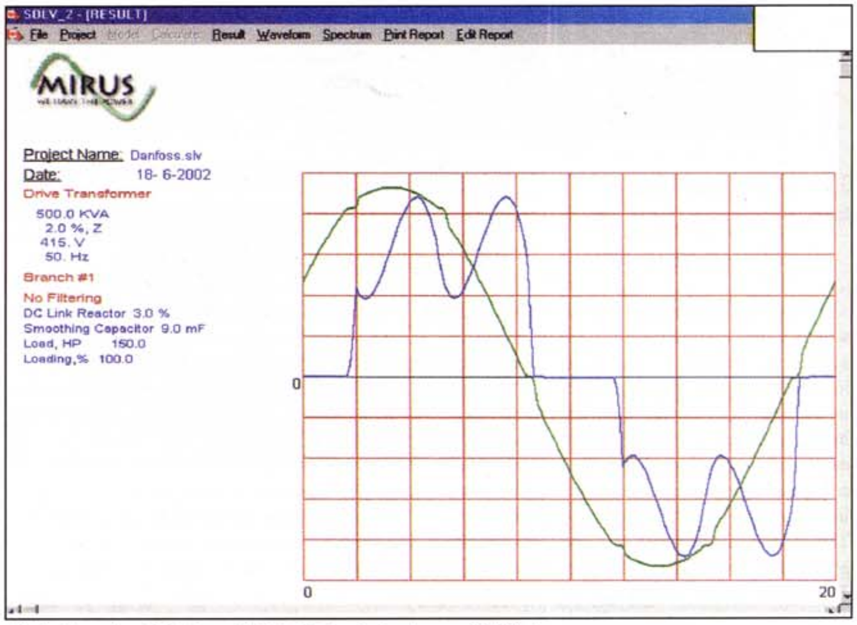


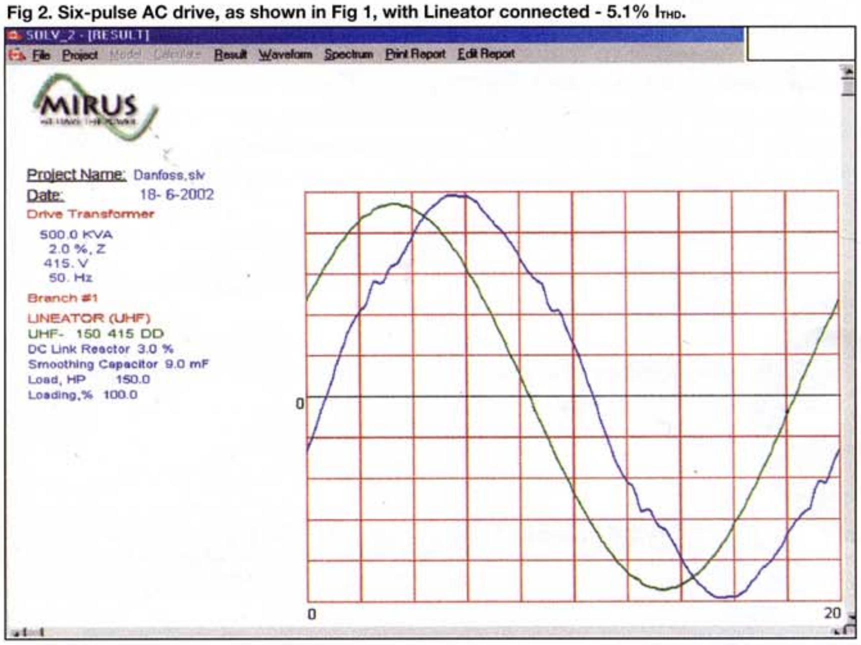
Fig 1. Six-pulse AC drive with 3% DC bus inductance - 39.5% I_{THD}.

The benefits of AC drives and induction motors are widely acknowledged. Their use has grown significantly as physical sizes and costs have decreased whilst reliability has increased considerably. An issue, however, which is giving increasing cause for concern throughout the world is the harmonic distortion of voltage supplies caused by the non-sinusoidal current drawn during the power conversion process inside drive converters.

The design of AC variable-frequency drives results in a pulsed current being drawn from the supply. In order to attenuate the magnitude of this pulsed current, drive designers install inductors in either the AC line or in the DC bus of the drive, or occasionally both. Fig 1 illustrates a typical AC six-pulse PWM drive fitted with a 3% DC bus inductor. In this example, the total harmonic current distortion (I_{THD}) is 39.5%.

Harmonics cause havoc in power systems, especially with generators or other 'weak' sources where impedances can be as high as 15%-18%, compared to 'stiff' sources (4-6%), more common on shore applications. The 'weaker' the source, the higher the voltage distortion, for a given harmonic current. Typical effects of harmonic distortion include :

Fig 2. Six-pulse AC drive, as shown in Fig 1, with Lineator connected - 5.1% I_{THD}.



- Overheating and sustained damage to bearings, laminations and winding insulation on generators, causing early life failure. Similar effects on transformers.

- Overheating of the stator and rotor of fixed speed electric motors; risk of bearing collapse due to hot rotors. This is especially problematic in explosion-proof motors with increased risk of explosion; in any case if the voltage distortion is over 6%, the motor is no longer certified.

- Spurious tripping of electrical circuit breakers. Interference with all onboard electrical, electronic and control system equipment, including navigation computers, radio communications, and lighting.

- Overheating of cables and additional risk of failure due to resonance. Decreased ability to carry rated current due to 'skin effect', which reduces a cables effective cross-sectional area.

Traditionally, drive manufacturers have used phase-shift transformers and modified drives to provide a greater level of harmonic attenuation, with 12-pulse being the most common. However, 18-, 24-, 36- and even 48-pulse designs are also used. 12-pulse mitigation provide levels of 'total harmonic current distortion' (I_{THD}) from ~15% for polygonal auto-transformers to 8%-10% for the more expensive double-wound types. Overall efficiencies of the drive systems fall, often by 4%-5% points, due to losses of the transformers under harmonic loads. In addition, the phase-shifted limbs of the transformers have to be carefully balanced otherwise the harmonic mitigation is significantly degraded.

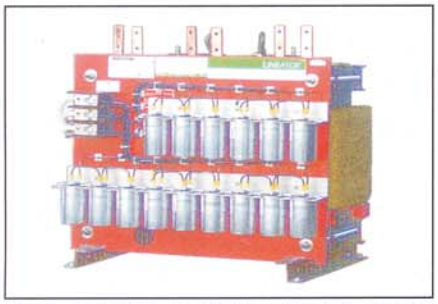


Fig 3. Example of a Lineator in open-chassis form.

More advanced solutions include active filters which inject compensation current on to the system to 'cancel out' a major portion of harmonic currents. Due to an active filter's low impedance (<1%), loads connected draw more harmonic current (~10%-15%) than would be the case with no active filter in circuit. This additional harmonic current needs to be taken into account when dimensioning the active filter. The increased harmonic current may also be problematic to other 'upstream' connected loads. The faster active filters can give excellent mitigation performance (<5% I_{THD}) but some inject into the power system excessive reactive current if the harmonic load is light or is switched off, causing generator tripping and other problems.

Active filters can be very expensive, often costing significantly more than the AC drives they are mitigating. Reliability is still very much an issue, especially on marine applications. Active filters are very complex products and on-site commissioning engineers are necessary to achieve optimum performance.

Over the last two years, a new and unique form of passive mitigation specifically designed for standard 6-pulse AC drives has been gaining popularity in North America. The Lineator, manufactured by Mirus International Inc, consists of a series-connected multiple winding input line reactor and small capacitor bank which can be applied to virtually any 6-pulse AC drive with a diode input bridge to dramatically reduce the harmonic current.

This revolutionary design achieves cancellation of all major harmonic currents, resulting in a I_{THD} of between 5% to 8% at full load operation. This dramatic reduction in harmonic currents is achieved through patented multiple reactor winding design, which creates an output voltage waveform shape to allow the drive input diodes to conduct current over a longer time span and with a substantially lower peak value.

Fig 2 illustrates the effect of the Lineator on the same AC drive shown in Fig 1. In Fig 1, the drive used a 3% DC bus inductor resulting in a I_{THD} of 39.1%. With the Lineator connected the I_{THD} dramatically dropped to 5.1%. For optimum performance, AC line reactors or DC bus inductors should be omitted from the drive, ideally making the drive slightly less expensive.

The unique feature of the Lineator is the three-phase reactor design consisting of multiple windings formed on a common core. This design allows for a smaller capacitor bank without sacrificing harmonic mitigation performance or introducing unacceptable voltage drops. Due to the low capacitive reactance (<15% of rated kVA), the Lineator is compatible with all forms of marine power generators.

A Lineator can be applied to individual or multiple 6-pulse AC drives and can be retrofitted to existing drives, enabling standard 6-pulse AC drives to achieve levels of harmonic mitigation normally associated with 18-pulse drives. In addition, the Lineator's low losses (>99% efficiency) result in overall efficiencies of the Lineator/drive combination being typically 3%-4% points better than 12- or 18-pulse designs. This is particularly important in marine applications where the cost of prime mover fuel is high.

The Lineator is currently available from 3kW to over 2500kW in voltages up to 750V. A variant currently under development, referred to as Lineator 2, is expected to provide off-the-shelf 12-pulse drives with 24-pulse harmonic performance. Lineator is supplied in chassis form for installation in drive cabinets or in stand-alone enclosures. Fig 3 depicts a typical Lineator open chassis.

Its rugged construction, simple design and inherent reliability, coupled with excellent harmonic mitigation performance and high efficiency are claimed by Mirus to make the Lineator a serious contender for the majority of thruster and other marine AC drive harmonic attenuation requirements.